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The NASA On-Board Propulsion Program

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Abstract

Almost all space missions require on-board propulsion for a variety of functions. In many cases, on-board propulsion systems are major spacecraft mass drivers impacting both mission cost and performance. Recent trends toward the use of smaller spacecraft and launch vehicles are expected to put further pressure on propulsion system performance. Because of this leverage, NASA's Office of Space Access and Technology (OSAT) sponsors an aggressive program to develop innovative high performance on-board propulsion technologies for both near- and far-term missions. The program addresses the needs of commercial and government space sectors and the applications set considered extends from large geosynchronous communications satellites to the miniature spacecraft planned by NASA's New Millennium program. The on-board program includes electric and chemical propulsion technologies and is committed to carrying new ideas from inception to insertion. An integrated On-Board Power and Propulsion Strategy has been developed to ensure that the pursuit of advanced electric propulsion systems is well. coordinated with OSAT's advanced power system development program. All program efforts emphasize both the development of commercial sources of technology and direct interaction with the user community. This paper provides an overview of NASA's On-Board Propulsion program with an emphasis on program directions and recent progress.

Introduction

On-board propulsion systems are required for a broad range of government and commercial mission classes. Figure 1 shows required propulsion functions for a variety of Earth-orbit and planetary missions. Mass fractions for several typical spacecraft are shown in Figure 2. These mass fractions clearly show that propulsion system wet mass is a dominant mass driver with mass fractions ranging from 20 - 40 percent for low and mid-Earth-orbit (LEO/MEO) satellites to more than 50 - 60 percent for geosynchronous (GEO) communications satellites and planetary spacecraft. For this reason on-board propulsion is an area of high leverage for improved mission performance. The benefits of advanced, high performance propulsion systems are beginning to be realized for mission functions such as the north-south stationkeeping (NSSK) of GEO comsats and high performance systems are being proposed for a number of next generation missions (see, for example, Refs. 1 and 2). In addition to the traditional missions involving large GEO spacecraft, small spacecraft missions are being proposed both in the commercial and government sectors. Emerging technology drivers include:

- Smaller Launch Vehicles
- Multiple Deployments per Launch
- Increased Payload Fractions
- Extended Spacecraft Life
- Deorbit Requirements
- Minimized Operations
- Environmental and Safety Concerns

All of these drivers will increase the demands for innovative, high performance on-board propulsion technologies both to meet NASA and

DOD mission requirements and to keep the United States competitive in the global marketplace for communications and Earth-observing satellites. NASA's Office of Space Access and Technology (OSAT) recognizes this national need for advanced on-board propulsion and maintains an aggressive program focused on maintaining and enhancing US leadership in space science and technology. Specific program objectives and content reflect NASA' s role as both a provider and a user of technology.

This paper provides an overview of OSAT's On-Board Propulsion (OBP) program with an emphasis on current technology efforts in the electric propulsion arena along with a description of anticipated technical directions over the next several years.

Program Description

The OBP program focuses on providing innovative new technologies for both near- and far-term missions. The program is committed to carrying new ideas from inception to insertion and therefore has a broad scope as shown in Figure 3. From the figure it can be seen that in addition to specific technology development efforts, fundamentals and technology insertion are critical program elements. The former ensures that the technology pipeline remains full - this element is carried out mainly through university and in-house efforts. The latter is designed to maximize the likelyhood of technology transfer and relies heavily on cooperative programs with industrial suppliers and commercial users.

To meet the broad set of known and anticipated mission requirements noted above, the OSAT program includes both chemical and electric propulsion elements. For LEO/MEO, GEO, and planetary spacecraft, chemical systems are the state-of-the-practice (SOP) for nearly all mission functions. Requirements for improved chemical systems are expected to extend into the foreseeable future. Specifically, chemical systems will be required where relatively high thrust maneuvers are required or where limited spacecraft power precludes the use of electric propulsion. As the need for very high performance systems grows in the near- and far-term, tremendous growth is expected in electric propulsion. Table 1 illustrates anticipated propulsion system trends for the various mission classes and indicates sustained requirements for both electric and chemical technologies with rapid growth in the electric propulsion area. Because electric propulsion and power are highly synergistic technologies, OSAT has developed an integrated On-Board Power and Propulsion Strategy (Refs. 3, 4) to coordinate the development of these critical technologies. This strategy assumes the acceptance of electric propulsion for most Earth-orbital missions within the next five years and for deep space missions within the next three to ten years. The overarching OSAT integrated program strategy goals are to:

1) ensure the technological superiority of on-board power and propulsion systems for current and planned NASA missions and U.S. commercial applications,

2) identify and aggressively pursue breakthrough technologies in on-board power and propulsion systems that enhance and enable future missions, and

3) sustain international leadership in on-board power and propulsion technologies.

While the integrated strategy was written mainly to focus and coordinate OSAT's space power and electric propulsion programs, it includes guidance for the chemical program as well. Thus, the entire OSAT on-board propulsion effort follows a singular strategic plan to advance the SOP to meet coming mission requirements. Past experience indicates that successful technology transfer requires an intimate knowledge of user needs and perceptions As a result, the program emphasizes close interaction with the user community - governement and commercial - and will focus on specific technology targets as opportunities for technology insertion arise. The program is structured to anticipate changing aerospace community requirements and has, in fact, undergone significant modifications over the past several years in order to align itself with NASA and industry pushes toward smaller spacecraft and reduced operating costs. Figure 4 shows an anticipated technology roadmap for on-board propulsion for NASA, commercial, and DOD mission applications through the next decade. The roadmap illustrates both recent program technology transfers and directions which will be described in the following sections.

Electric Propulsion

As noted above, the benefits of electric propulsion are now being realized in commercial missions with tremendous growth in the application of electric propulsion systems expected over the next ten years. Anticipated near-term applications of electric propulsion technologies are shown in Figure 4. These include the 600 second arcjet for commercial comsat NSSK (Figure 5 and Ref. 1) and ion thruster technology for ambitious space science missions. The 600 second, 2 kW-class arcjet system development program was undertaken in response to a known user need and to provide technology for anticipated LEO/MEO satellite insertion and deorbit requirements. Under this joint NASA/industry program an industrial source of the technology was developed (the Olin Aerospace Co. (OAC)) and a successful qualification-level life test of a flight-type arcjet system was recently completed. This high performance arcjet technology has now been accepted for use on a next generation commercial comsat series and the first flight is scheduled for 1996. NASA's Solar Electric Propulsion Technology Application and Readiness (NSTAR) program was initiated in FY93 and has baselined 30 cm ion engine technology developed under the OBP program. The NSTAR program is managed by the Jet Propulsion Laboratory with the Lewis Research Center as the technology provider. NSTAR will provide a 0.5 - 2.5 kW, 55% efficient ion system (Isp ~ 3100 sec) that will enable launch vehicle class reductions as well as significant trip time savings for small satellite planetary missions (Ref. 5). This technology will also be applicable to advanced Earth-orbital missions with high delta-V requirements (e. g. NSSK and repositioning of large military spacecraft). Hughes was recently chosen as the contractor for the flight hardware. The NSTAR system is a prime candidate for application in early planetary missions being proposed to NASA's New Millennium initiative and the program is geared to provide flight ion systems for the first New Millennium launch in FY98.

In addition to the NSTAR program, the OSAT program is focusing on the development of several specific technologies for commercial and government mission applications in the 3 to 5 year time frame. These include the Pulsed Plasma Thruster (PPT), the Low Power Arcjet Thruster (LPAT), and the Low Power Russian Hall Thruster (RHT).

PPT's utilize solid teflon propellant and provide over 1000 s of specific impulse while operating at power levels between 2 and 60 watts. Power throttling is achieved by changing the pulse rate with no loss in performance and use of solid teflon propellant results in a very simple (i.e., one moving part), lightweight, low-cost feed system with no hazardous propellant handling or storage concerns. This combination makes PPTs uniquely applicable to a range of small spacecraft and opens the potential user base greatly (Ref. 6). PPT simplicity also lends itself to use on autonomous spacecraft, given both the minimal telemetry needed for system health monitoring and the demonstrated shelf-life of approximately 20 years. PPT's have demonstrated an impulse bit range from 20 μN-s to 300 μN-s, three orders-of-magnitude below that possible with available hydrazine engines (13 mN-s). This capability can be used in space science missions for extremely fine orbit control for interferometry or in small body encounters. Recent analyses have shown that PPT's can be used for drag make-up to greatly extend the on-orbit life of small commercial comsats (details proprietary). The technology could also provide significant weight savings for small Earth science spacecraft. An example of the benefits of PPT's for a sun synchronous orbit transfer-class mission (the Total Ozone Mapping Spectrometer (TOMS)) is shown in Figure 6. For this, the state-of-art monopropellant system baselined for TOMS was replaced with a PPT system with the ground rule that no additional power would be required to perform the mission. The analysis shows that the use of the PPT increases the science payload by a factor of approximately 1.5 for the baseline mission. Alternately, the weight savings could be used to reduce spacecraft launch mass by the same amount. The figure also shows that the PPT-derived benefit increases to over a factor of two if a deorbit requirement (anticipated for most future missions) is included. The OBP program is now in the middle of a two phase PPT technology development program which was initiated in 1994. The first phase is directed at reducing the PPT system mass by a factor of two while simultaneously doubling total impulse capability, resulting in at least a factor of four increase in propulsion system capability per unit launch mass. This effort is being performed under a contract with the OAC and should produce and demonstrate a flight-type system in FY97. The Phase 2 effort will further miniaturize the technology for future applications. In addition to the contracted effort, the OBP program maintains strong in-house and university programs directed toward advanced PPT development. The former is designed to characterize all aspects of PPT operation and assess/address spacecraft integration. This takes full advantage of existing space propulsion testbeds (e.g. performance measurement, EMI, plume impacts capabilities) that will also be used extensively throughout the Phase 1 and 2 contracted efforts. One recent output of this effort is a high precision thrust stand that will be used extensively in the PPT program (see Figure 7 and Ref. 7). The university program (at the Ohio State University) has two major goals. The first is the development of a high fidelity numerical PPT model. This effort leverages significant past code development efforts (MACH 2) and is beginning to produce meaningful results. The next step will be to use the code as a design tool for next generation PPTs. The second focus is the development of a new high performance fuel for next generation PPT's. At this point, layered polymer combinations that provide higher average specific impulse characteristics but avoid electrode carbonization problems encountered in previous advanced fuel development efforts are being tested (Ref. 8). At present, the OBP program is working with several potential users for the PPT. These include commercial concerns and the New Millennium program. The program is also involved (via Interagency Agreement) with the Joint Air Force Weber State University Satellite (JAWSAT) program, which will demonstrate PPT technology on an educational small spacecraft flight.

Sub-kW low power arcjet thrusters (LPATs) can provide approximately 500 s of specific impulse for a number of potential mission functions now performed with conventional hydrazine thrusters (Isp ~ 225 s). This performance increase can be used to extend mission life, reduce propellant mass requirements by more than a factor of 2, or improve payload capabilities. LPATs were proposed as a propulsion option in a recent Discovery Program proposal entitled the Near Earth Asteroid Returned Sample (NEARS) mission and submitted by the Applied Physics Laboratory with LeRC as a team member responsible for the propulsion system. For this mission, replacement of the baselined 220 N bipropellant rocket with a 0.5 kW arcjet increased the stay time at the target asteroid by a factor of 2 (from 70 to 140 days), simplified spacecraft design (single propellant system), and increased dry mass contingency by more than a factor of two without impacting the power system. LPATs were also recently considered for NSSK on a power limited DOD spacecraft. In the DOD study, arcjets were found to be the only viable propulsion option capable of meeting mission life goals. The OBP LPAT program is currently targeting a commercial technology demonstration spacecraft for first application and a contractual effort that will provide a demonstration of flight hardware in FY97 is underway. LPATs are prime candidates for insertions of distributed communications spacecraft, and one major OBP program target is a technology demonstration flight in 1998. OBP personnel have also had recent discussions with Goddard Space Flight Center propulsion system engineers LPAT applications to Earth science missions. In addition to the 0.5 kW-class arcjet development effort, the NASA program also supports feasibility research on sub-0.25 kW for very small spacecraft (Ref. 9).

Russian Hall thrusters (RHT) have generated significant interest in the aerospace community over the past several years. There are two basic variations of this type of device, the stationary plasma thruster (SPT) and the thruster with anode layer (TAL). Specific impulse capabilities of these devices are on the order of 1600 s at 0.50 efficiency. SPT's made by Fakel Enterprises are operational (at two different power levels, 0.66 kW and 1.35 kW) on Russian Earth-orbiting satellites and the 1.35 kW version is now being readied for commercial use on western commercial GEO comsats (Ref. 2). Lifetimes of 6000 hours were recently demonstrated for the 1.35 kW thruster (Ref. 10) and extensive evaluations of integration impacts have been undertaken (see, for example, Ref. 11). Sub-kW Hall thrusters are now being considered for several missions including space science. An example of this is illustrated by the MIT Energetic Transient Array (ETA) mission that will be proposed to the MIDEX program. In ETA, a set of eight small spacecraft will be distributed in heliocentric orbit to determine the source of gamma ray bursters in a logical follow on to the Gamma Ray Observatory. Existing SPT technology (obtained by the Phillips Laboratory) operated in a derated mode would be used to place the spacecraft in their required positions. The high specific impulse levels (1600+s) of these xenon Hall electrostatic thrusters allow on-board propellant to be reduced by several factors when compared to existing chemical systems and the OBP program will support ETA via extensive propulsion system demonstrations in the ground test element of the program.

Also in the area of Hall thrusters, the OBP has worked closely with the Ballistic Missile Defense Organization's Directorate for Innovative Science and Technology (BMDO) to evaluate RHT technology for several missions. At present, the BMDO program focuses on the development of a 1.5 kW Hall thruster "system "on-a-pallet" to be demonstrated in a near term flight test (Ref. 12) and OBP personnel are managing this effort.

Sub-0.5 kW RHT's may offer very high performance levels for power limited applications but have not yet been demonstrated. To evaluate this option an OBP program was initiated in FY95 to develop with the Russians a 0.25 kW SPT thruster and a 0.5 kW TAL thruster. The two thrusters are engineering models and will be evaluated by the end of CY95. Further development efforts will be decided following these thruster demonstrations.

For farther term missions (5 to 10 years), the OBP program is initiating efforts to develop a very high efficiency (> 0.6), low-mass propulsion systems with an end-to-end system specific mass (including power) and lifetime goals of 10 kg/kW and 15,000 hours, respectively. These attributes were chosen to enable 1) three to five year trip times for complex space science missions with small spacecraft and 2) electric orbit transfers (LEO to GEO-class) with high payload fractions and relatively short trip times (sub-3 month). At least two electrostatic concepts, an advanced gridded ion system and a Hall thruster-based system, will be evaluated under the OSAT program. Concept feasibility assessments will be conducted in FY96 and FY97. It is anticipated that these evaluations will lead to a technology downselect for a directed development program.

The advanced gridded ion thruster program will target a system with twice the NSTAR life capability and greater than a factor of two reduction in power processing system mass. Several potential grid technology options will be explored and full advantage will be taken of recent developments both in the OSAT OBP and Advanced Concepts programs. Development of simple, low-mass plasma generation and ion extraction power delivery systems will involve examination of high voltage power bus technology, new power converter concepts, and advanced power distribution methods. In the Hall thruster area, new technology efforts will focus on the feasibility of long-lived, single and two stage systems capable of specific impulse values of approximately 3000 seconds while still maintaining system simplicity. Work is in progress to demonstrate direct drive for the first acceleration stage of the Hall thruster.

Finally, the OBP program is initiating a fundamental effort to develop an electric microrocket system for very small (≤ 10 kg) spacecraft. As spacecraft are greatly miniaturized over the next decade, innovative new propulsion systems will be required to meet mission performance requirements. By moving to smart microspacecraft the way is opened for drastically reduced launch vehicle requirements. Propulsion will, however, still be a long pole in the tent and the age of microspacecraft will present new challenges for propulsion system designers. Specifically, pressure will be exerted to develop very low power, relatively high performance, simple, low mass systems that can be easily integrated into the spacecraft. The simplicity of these systems should make them amenable to autonomous operation and, where possible, a fully integrated philosophy will be employed. As in the case of the high performance electrostatic system discussed above, the OSAT program effort will first focus on the evaluation of several microelectric concepts with a goal of downselecting to a single focused development effort in the FY97 time frame. At this time, candidate systems include integrated electrothermal thrusters, colloidal thrusters, field emission thrusters, and miniaturized electrostatic systems. The first phase of the development program will consist of both in-house and university-based studies.

Chemical Propulsion

While electric propulsion systems are now being broadly considered, chemical propulsion is the SOP for nearly all in-space propulsion functions. A continuing market for on-board chemical systems is anticipated. In fact, at this point in time nearly every major spacefaring nation has a development program for high performance chemical systems for orbit transfer and many also support development efforts aimed at next generation auxiliary systems. Thus, the development of new, high performance chemical systems will likely be required to keep the U.S. competitive in the global market place. In the recent past the OBP program has transferred technology both to the commercial sector and to a NASA science mission. The former was based on the breakthrough iridium-coated rhenium (Ir-Re) rocket chamber technology developed under the OBP program (Ref. 13). The Ir-Re combination provides a significant advantage over SOP silicide-coated niobium technology and was demonstrated extensively under a joint LeRC/TRW program. Ir-Re rockets have now been baselined for next generation GEO comsat applications. For the Advanced X-Ray Astrophysics Facility (AXAF), a rocket incorporating front end cooling technology developed under a joint LeRC/TRW program was chosen for the final orbit insertion function. This advance provides a significant increase in specific impulse and also simplifies the rocket design (reducing manufacturing costs). Improved performance will increase attainable apogee which, in turn, will greatly enhance the science return per orbit in this high profile NASA mission.

The chemical propulsion program continues to pursue high quality, low cost manufacturing technologies for Ir-Re rockets with a goal of reducing manufacturing costs by a factor of three. Both new Ir-Re chamber manufacturing and joining techniques are being studied (see, for example, Refs. 14 and 15). The program is also actively pursuing the insertion of Ir-Re technology into the nitrogen tetroxide-monomethyl hydrazine rocket community through a Space Act Agreement with the Atlantic Research Corp.

The holy grail for the chemical propulsion program is a rocket material that can run any propellant combination at arbitrary mixture ratios. While the development of Ir-Re technology was a step in the right direction the OBP continues to evaluate advanced rocket chamber materials combinations. Promising options now under consideration include ceramic oxide-coated Ir-Re and hafnium carbide-doped with tantalum carbide on a graphite fiber preform. The former recently survived extended duration (39 hrs) testing on gaseous hydrogen/gaseous oxygen mixtures. Short tests with the hafnium carbide indicated that further densification of the material in the matrix will be required.

A major new thrust of the OBP chemical program is aimed at the development of an advanced monopropellant thruster. SOP monopropellant rockets use hydrazine and offer about 220 sec of specific impulse with a propellant density of 1.0 gm/cc. Hydrazine is a toxic liquid with toxic vapors requiring costly procedures and handling equipment. As a result, manufacturing and ground operations costs are high for hydrazine systems. Additionally, hydrazine freezes at 2°C which means that spacecraft thermal control is required in most mission scenarios. Over the next two years, the OBP program will focus on the development of an advanced monopropellant based on liquid gun propellants (see Figure 8).

The monopropellant of greatest interest at this point is composed of an oxidizer (hydroxylamine nitrate or HAN) and a fuel (triethanolamine nitrate or TEAN) which are dissolved in water. Both the projected specific impulse from this combination (~270 s) and its storage density (1.4 g/cc) are significantly above SOP. Perhaps the major advantages, however, relate to the physical properties of the combination. It is very low in toxicity, is neither explosive nor a fire hazard, and has a vapor head consisting essentially of water vapor. These characteristics are expected to greatly mitigate the costs related to the environmental and safety issues associated with conventional hydrazine-based systems. Also, the freezing point of the HAN/TEAN combination (-40°C) is substantially below that of hydrazine and this greatly alleviates system thermal control requirements. Finally, the U. S. Army has made a significant investment in the characterization and production of the proposed monopropellant constituents for use as liquid gun propellants over the past several years. This investment can be heavily leveraged to reduce overall program costs (i.e. propellant is expected to be inexpensive and readily available). At present, the OSAT program plans to initiate at least one and probably two, contractual efforts to develop advanced monopropellant engines. Initiation of the contracted program(s) is anticipated in August of 1995.

The OBP program also supports a high pressure/miniaturized rocket technology development program. Operation of radiation-cooled rockets at chamber pressures up to 500 psia can provide improved performance while significantly reducing the engine size and weight. For example, projections indicate that by going from the SOP 100 psia to 250 psia, the thruster envelope could be reduced 70 percent. In the past, operation of low thrust engines (< 440 N) at high chamber pressures has not been possible because of the high heat fluxes generated. Furthermore, the presence of heavy, high-pressure tanks would cancel performance benefits. The maturation of high-temperature, oxidation-resistant chamber materials has provided the thermal margin to operate at high chamber pressures. Concurrently, lightweight, high-pressure tanks have been developed and the size and mass of propulsion system components have been greatly reduced in technology development programs sponsored by BMDO. Several innovative system level pressurization schemes are under consideration. In the recent past, technology programs were conducted with Gencorp Aerojet and TRW to establish the feasibility of operating at high chamber pressure and to determine the effect of chamber pressure on heat transfer and combustion efficiency (Refs. 16 and 17). Both programs demonstrated steady-state combustion within the thermal limits of OSAT-sponsored Ir-Re technology at chamber pressures up to 600 psia. No problems were encountered with combustion stability in either program. For a 440 N engine operating with nitrogen tetroxide and hydrazine (NTO/N2H4) propellants, Aerojet demonstrated a performance of 333 sec at 250 psia chamber pressure and 300:1 area ratio. For a 220 N NTO/N2H4 engine, TRW demonstrated a performance of 337 sec at 500 psia chamber pressure and 150:1 area ratio. At the same chamber pressure and area ratio, TRW established a non-optimized performance of 327 sec for a 50-lbf engine operating with NTO/MMH propellants. A schematic of TRW's 220 N engine is shown in Figure 9. It should be noted that the quoted performance numbers were generated in programs designed to establish concept feasibility and should be considered only as the current baseline. Further optimizations may be possible. TRW was selected to develop a flight-type, 220 N engine with an operating pressure of 500 psia. The program will now focus on optimization of thermal control in the head-end region of the rocket and development of a low cost manufacturing process for high temperature rocket chamber materials.

Concluding Remarks

On-Board propulsion is a major mission performance driver for a broad range of space applications. Innovative, high performance propulsion systems will be required to meet known and anticipated mission performance goals in both the near- and far-term. To meet these national requirements, NASA's Office of Space Access and Technology sponsors an aggressive on-board propulsion research and development program. Both chemical and electric technologies are included to cover a wide range of high leverage mission functions. Because of the synergy between electric propulsion and advanced space power, the electric propulsion element is carefully coordinated with OSAT's Space Power program. Strong emphasis is placed on technology transfer and program efforts are directed toward the development of commercial technology sources and the demonstration of program technologies to the level required by potential users. OSAT's On-Board Propulsion program is committed to sustaining U.S. leadership in this critical area well into the next decade and invites interactions with the community to help meet this goal.

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Table 1. Anticipated On-Board Propulsion Trends.

FUNCTION	ISSA	LEO/MEO	GEO	PLANETARY
• INSERTION	N/A	● → ○/□	● → ○/□	● → ○/□
• ORBIT CONTROL	●	●/■ → ○/□	●/■ → □	● → □
• REPOSITIONING	●	● → ○/□	● → □	● → □
• DEORBIT	N/A	● → ○/□	N/A	N/A
• SAMPLE/RETURN	N/A	N/A	N/A	● → ○/□

○ - CHEMICAL; □ - ELECTRIC
CLOSED SYMBOLS - SOA; OPEN SYMBOLS - ANTICIPATED TRENDS

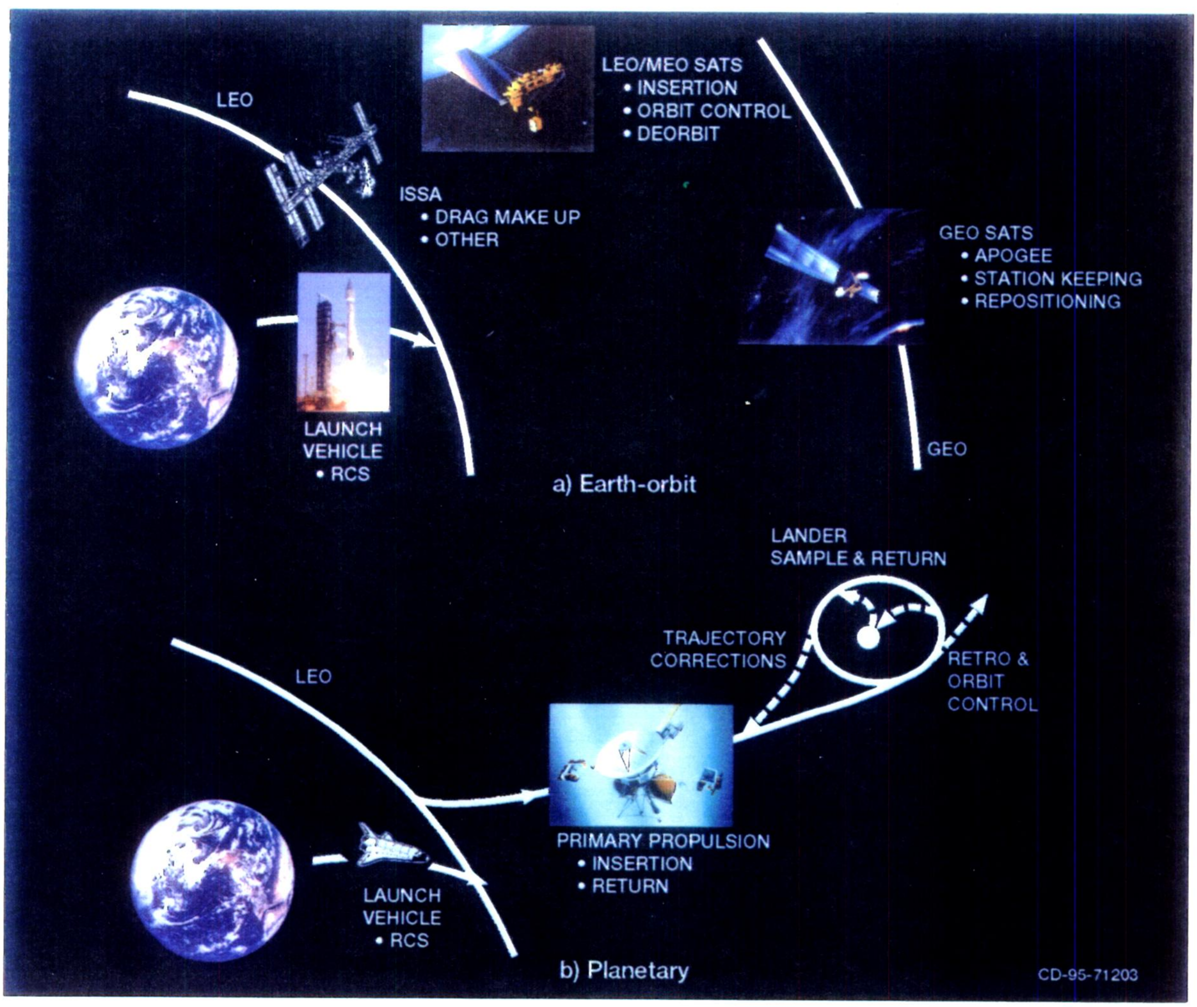


Figure 1. On-Board Propulsion Functions.

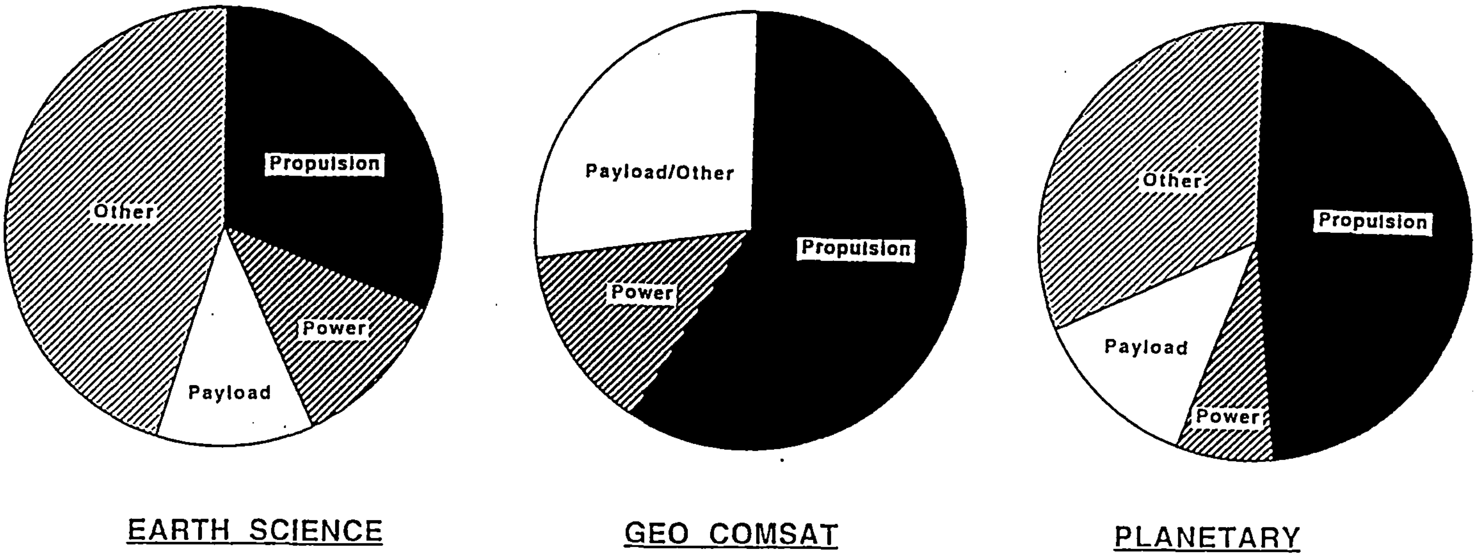


Figure 2. Typical Spacecraft Mass Fractions.

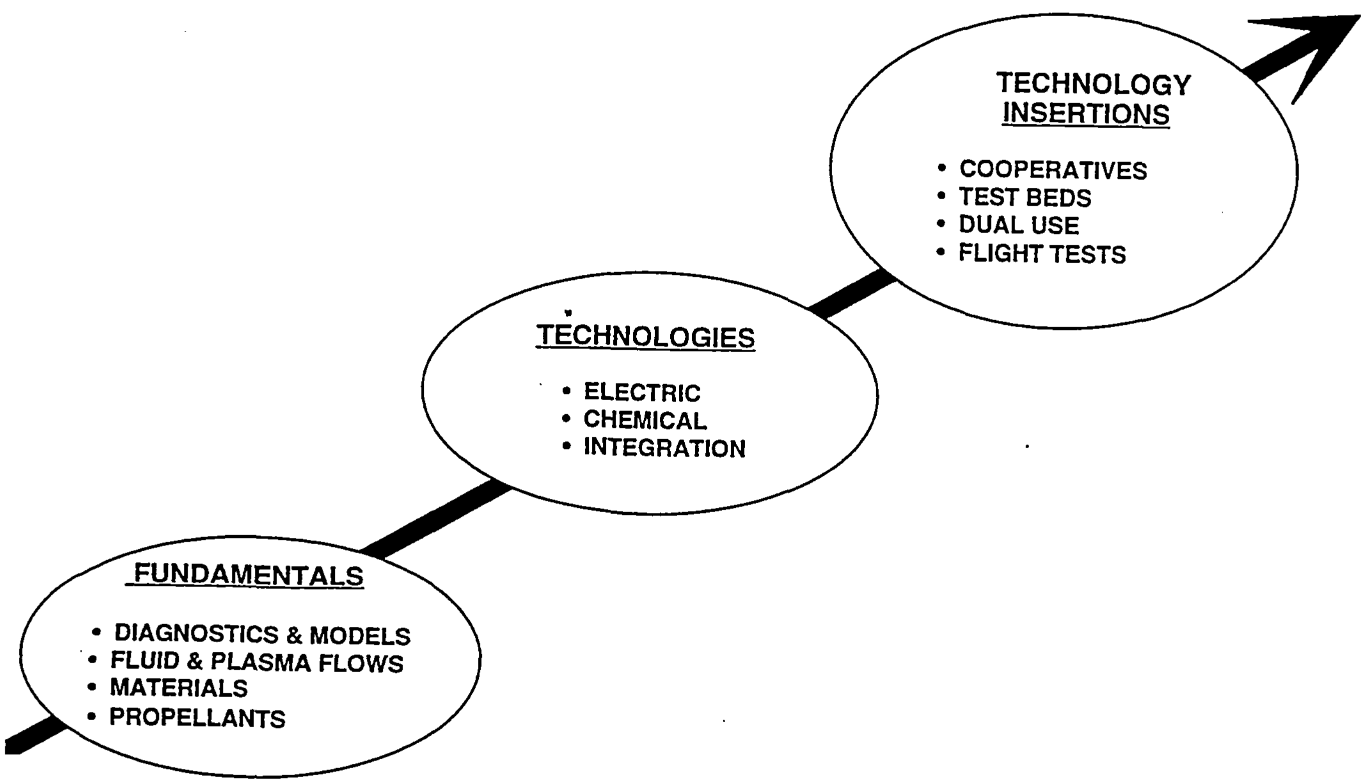


Figure 3. On-Board Propulsion Program Scope.

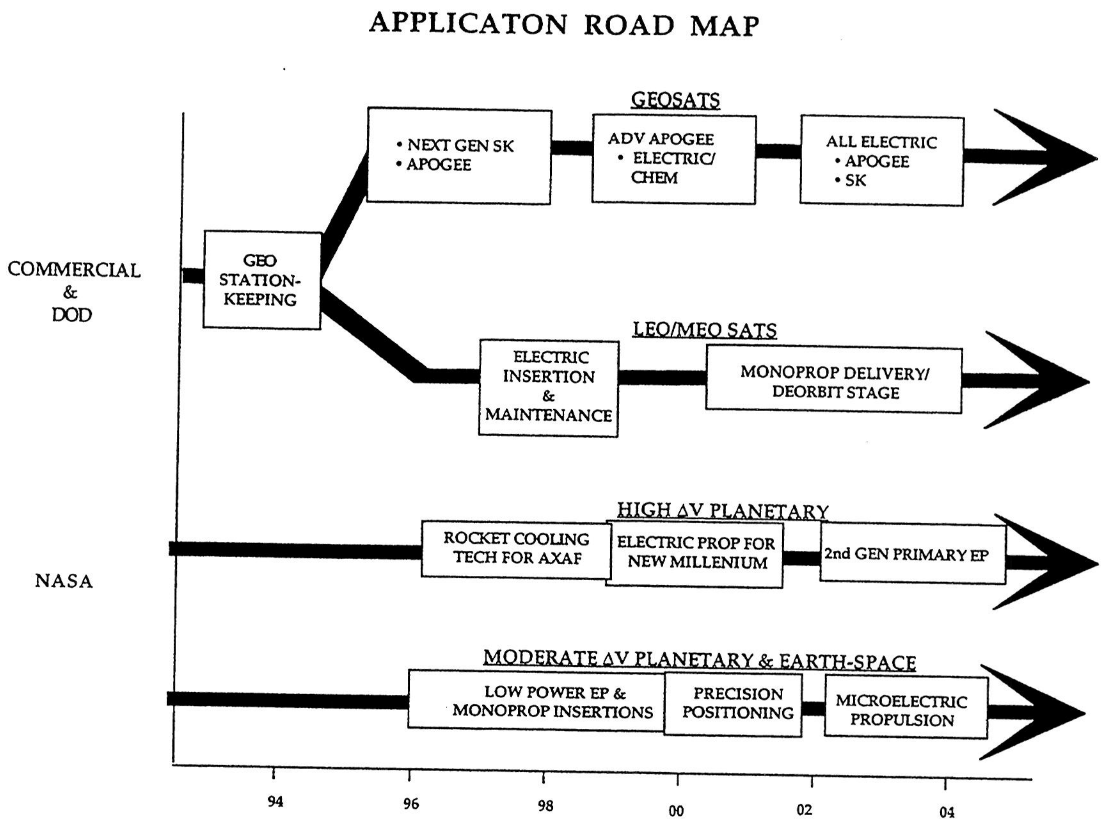


Figure 4. On-Board Propulsion Technology Roadmap.

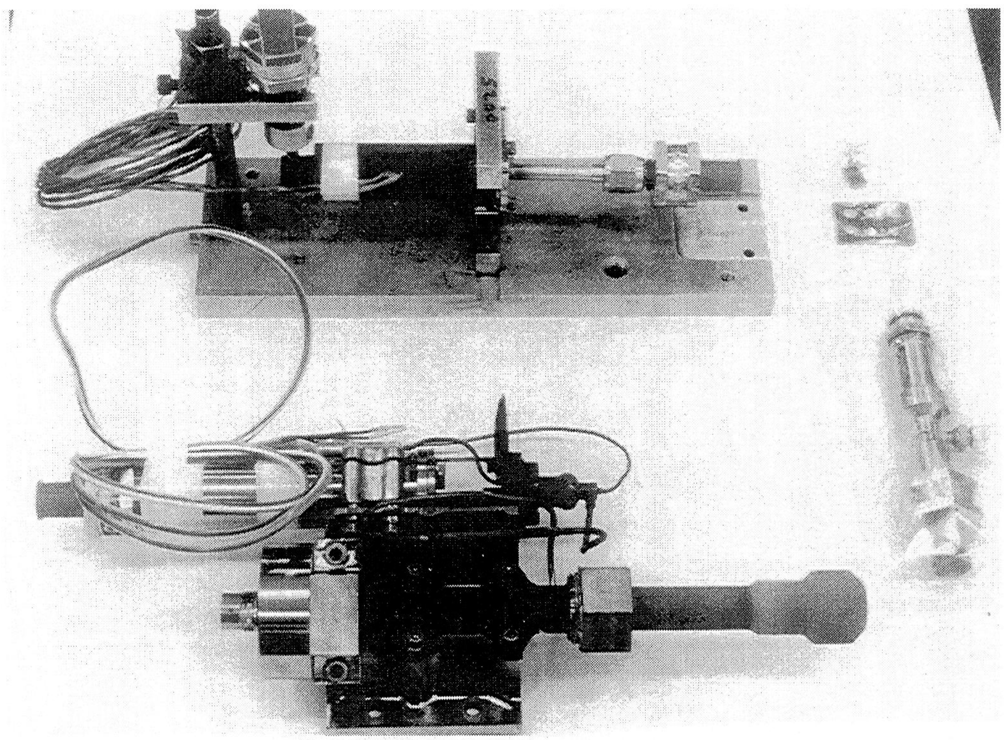
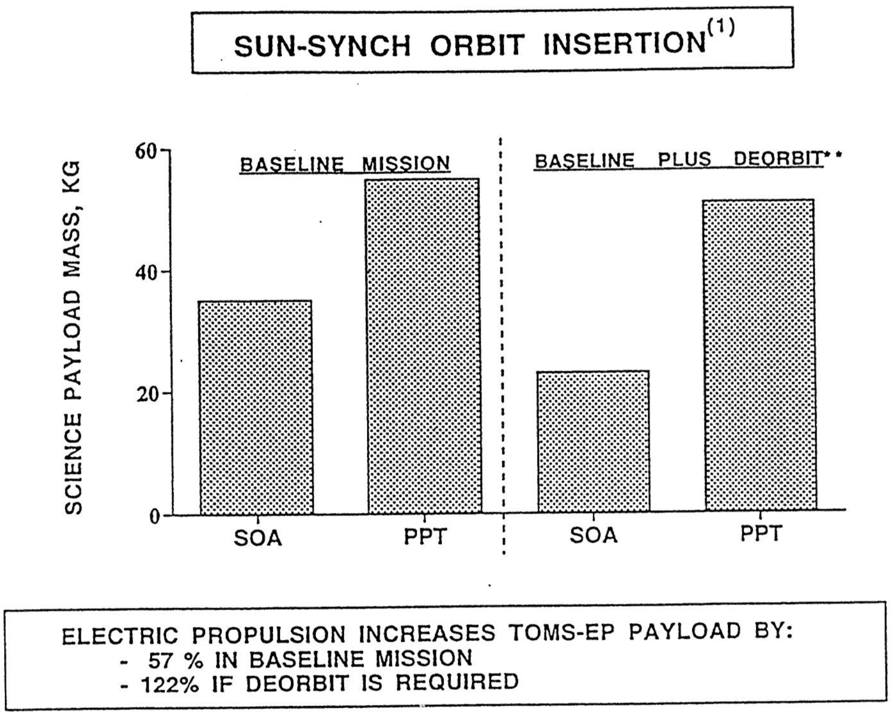


Figure 5. 600 Second Arcjet Thruster.



(1) TOMS-EP MISSION, LAUNCH MASS OF 287 KG, FINAL ORBIT ALTITUDE OF 955 KM, 80 DAY INSERTION

** DEORBIT TO 500 KM.

Figure 6. PPT Benefits Example - Sun Synchronous Orbit Transfer Mission.

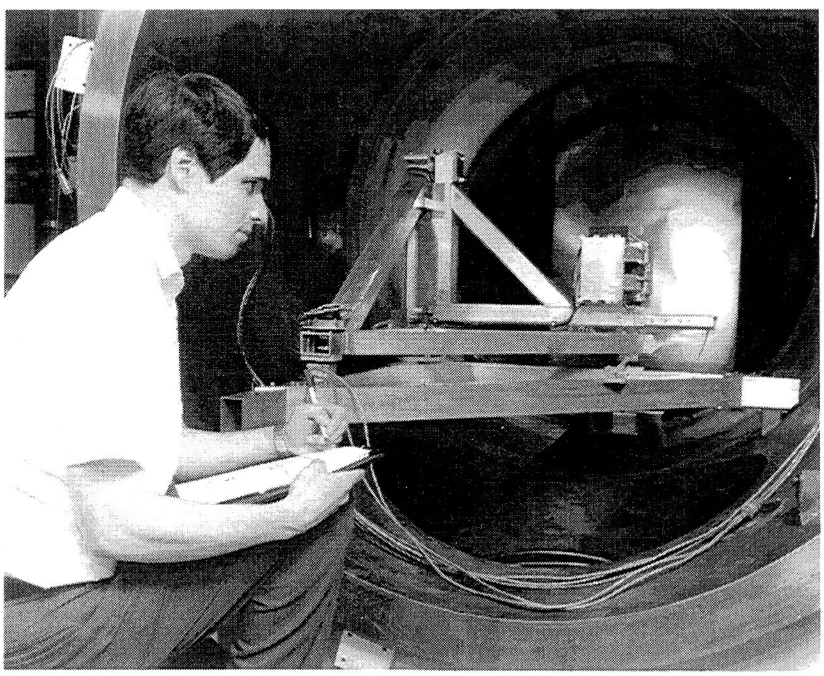
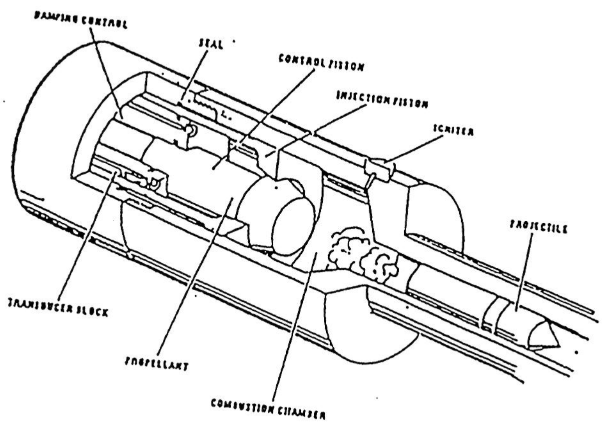


Figure 7. PPT Thrust Stand.

LIQUID PROPELLANT 1846 CHOSEN FOR DEVELOPMENT BY ARMY FOR GUNS



ADVANTAGES

- SIMPLICITY OF MONOPROP
- HIGH PERFORMANCE (~270s Isp)
- HIGH DENSITY (1.43 gm/cc)
- STORAGE/HANDLING
  - LOW TOXICITY
  - NON-EXPLOSIVE
- LOW COST

Figure 8. Potential Advanced Monopropellant Example.

HIPES FLIGHT ENGINE CONCEPT CUTAWAY

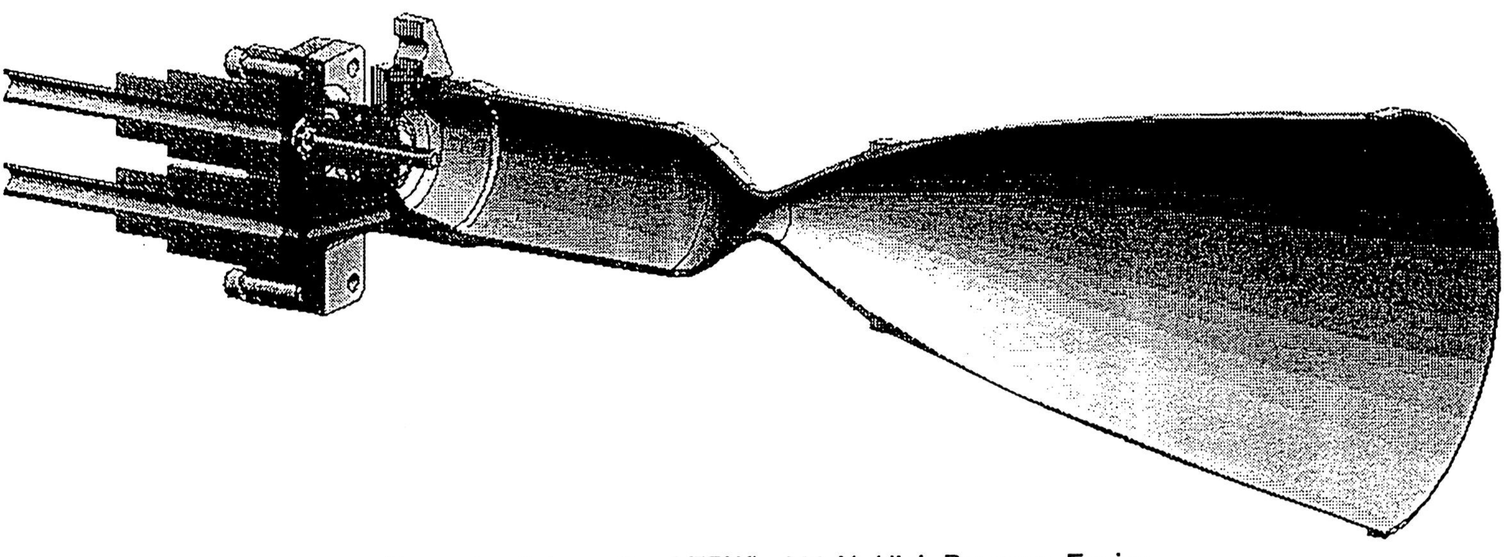


Figure 9. Schematic of TRW's 220 N, High Pressure Engine.

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13. ABSTRACT ***(Maximum 200 words)***

Almost all space missions require on-board propulsion for a variety of functions. In many cases, on-board propulsion systems are major spacecraft mass drivers impacting both mission cost and performance. Recent trends toward the use of smaller spacecraft and launch vehicles are expected to put further pressure on propulsion system performance. Because of this leverage, NASA's Office of Space Access and Technology (OSAT) sponsors an aggressive program to develop innovative high performance on-board propulsion technologies for both near- and far-term missions. The program addresses the needs of commercial and government space sectors and the applications set considered extends from large geosynchronous communications satellites to the miniature spacecraft planned by NASA's New Millennium program. The on-board program includes electric and chemical propulsion technologies and is committed to carrying new ideas from inception to insertion. An integrated On-Board Power and Propulsion Strategy has been developed to ensure that the pursuit of advanced electric propulsion systems is well coordinated with OSAT's advanced power system development program. All program efforts emphasize both the development of commercial sources of technology and direct interaction with the user community. This paper provides an overview of NASA's On-Board Propulsion program with an emphasis on program directions and recent progress.

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